Retrieving Ionospheric Electron Density Distribution with COSMIC Occultations

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LONG-TERM GOALS

Profiles of ionospheric and atmospheric variables derived from GPS/MET occultation data can be used to advance meteorology, climate, and space weather research. Our long-term goals are to develop high-quality algorithms for extracting bending angles, refractivity profiles, and ionospheric and atmospheric profiles from the GPS/MET (and future COSMIC) occultation data.

OBJECTIVES

Our major objective is to develop high-quality processing algorithms to extract bending angle and distribution of ionospheric (electron density) and atmospheric (temperature, pressure and water vapor) variables from GPS/MET occultation data. Long-term objective on this matter would be to design operational retrieval algorithms for the COSMIC mission.

Our secondary objective is to improve data processing schemes to derive total electron content (TEC) and precipitable water (PW), and line-of-sight (LOS) TEC and PW from ground-based GPS data. The long-term objective on this matter would be to develop real-time data processing capability for meteorology and space weather investigations.

APPROACH

Many tasks are required to accomplish the major and secondary objectives. The PI is in charge of the management and guidance of the project. He leads a research team of seven active participants sharing the tasks to accomplish the objectives. Those participants who made significant contributions to this project (especially in developing occultation algorithms) include the PI, Mr. Cheng-Yung Huang, and Dr. A.G. Pavelyev. The other participants who made moderate or minor contributions include Mr. Jack Hu, Mr. Yu-Jen Lin, Chen-Ching Chiang, and Mr. Dong-Ying Tsai. Dr. Pavelyev was a visiting professor at the CSRSR from February to July 2002 supported by a grant given to the PI. Mr. Jack Hu, a technician at CSRSR, is a computer expert. Mr. Huang, Mr. Lin, Mr. Chiang, and Mr. Tsai are graduate students of the PI.

WORK COMPLETED

Work with a scientific significance and reported in the literature include two major aspects. First, two Master Thesis were completed (Lin 2002; Lin et al. 2002; Tsai 2002). Lin (2002) and Lin et al. (2002) developed a tomographic model to reconstruct 3D wet refractivity structures of the troposphere from

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14. ABSTRACT
Profiles of ionospheric and atmospheric variables derived from GPS/MET occultation data can be used to advance meteorology, climate, and space weather research. Our long-term goals are to develop high-quality algorithms for extracting bending angles, refractivity profiles, and ionospheric and atmospheric profiles from the GPS/MET (and future COSMIC) occultation data.

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simulated ground-based GPS observations. Mr. C.C. Chiang is improving the tomographic model. Tsai (2002) studied ionospheric irregularities by using ground-based GPS measurements. Second, occultation data processing algorithms were developed to retrieve atmospheric and ionospheric variables for scientific investigations (Liou et al. 2002a, 2002b; Pavelyev et al. 2002a, b, c, d).

Work done with a moderate progress is addressed in two categories. First, occultation retrieval algorithms are being developed using the Canonical transform. We utilized the Abel transform, amplitude method, and holographic method to process the occultation data, and reported the results in the literature. Second, real-time ground-based GPS data processing schemes are being developed. Supporting work on this matter includes investigations on mapping functions, short baseline impact on GPS positioning accuracy, and development of atmospheric model.

RESULTS

A tomographic model was developed to reconstruct 3D wet refractivity structures of the troposphere using ground-based GPS measurements (Lin 2002; Lin et al. 2002). Figure 1 shows the retrieved wet refractivity structures based on simulations and the corresponding RMSEs. The results are reasonable with errors ranging from 5 to 10% below 4-5 km altitude especially with constraints at the surface and top of the atmosphere. Since water vapor primarily distributes in the lower atmosphere, it is of larger concern to have the model to perform better in the lower boundary layer, typically within the bottom several kilometers of the atmosphere.

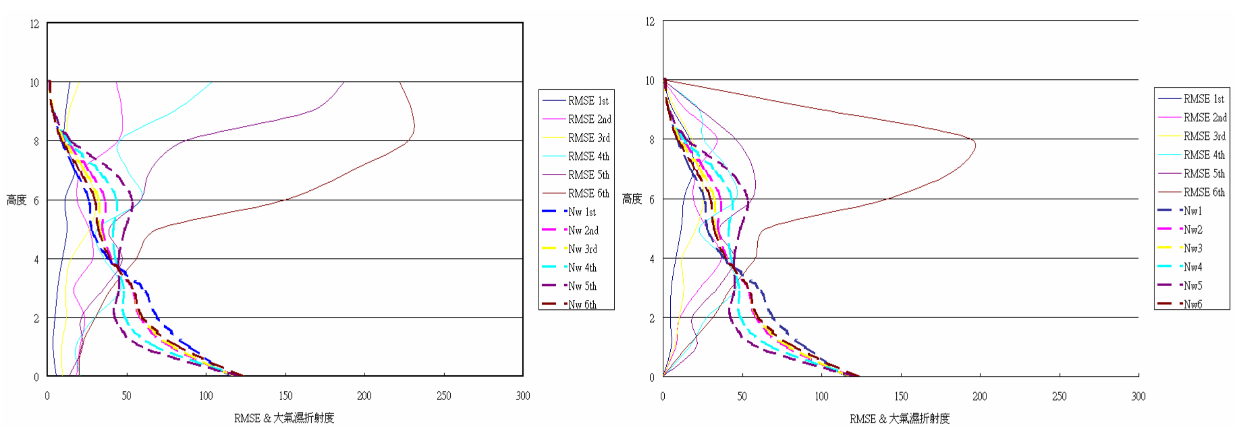

Figure 1. Reconstructed 3D wet refractivity structures and the associated RMSEs for (a) without and (b) with constraints at the surface and top of the atmosphere.

Ionospheric irregularities due to electron density distribution were studied and presented in Tsai (2002) by using ground-based GPS measurements. It was shown that the second derivatives of the GPS phase carriers (or TEC) or amplitudes link to ionospheric irregularities or scintillations as seen in Figure 2 for (a) quiet conditions, and (b) active ionosphere in the F layer. A knowledge of the irregular phenomena will help improve real-time GPS positioning accuracy (especially during night time), design (especially for long wave) communications systems, and improve space weather research.

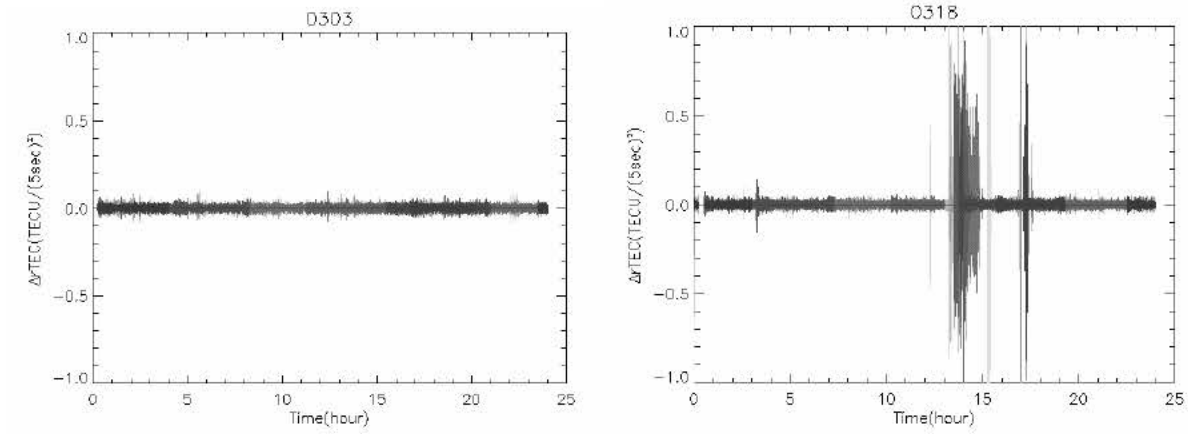

Figure 2. Ground-based GPS observed ionospheric scintillation phenomena.

The refractivity and temperature vertical gradients were retrieved from the amplitude of the radio occultation as shown in Figure 3 (Liou et al. 2002b). In Figure 3 (a), curves T1, T2 and UCAR correspond to temperatures retrieved from amplitudes of RO signals at frequencies F1, F2 and UCAR data. Curves T1, T2 and UCAR are displaced by 180 °K. Curves dT(F1)/dh, dT(F2)/dh (displaced by 5 units) show variations in the vertical gradient of temperature [°K/km]. The main temperature minimum occurs at the height of ~16.8 km. This position corresponds to results of retrieved temperature profile of UCAR. Positive values of dT(h)/dh are seen in the tropopause region at levels 15, 17, 19.5 km. Negative values of dT(h)/dh ~ 7...9 °K/km are observed at levels 13, 16, 18 and 20.3 km. The features in the vertical gradient distribution may correspond to wave structures in the tropopause with vertical periods of about 2-3 km. In Figure 3 (b), two maximum values of the positive gradient of about $29 \cdot 10^9$ and $28 \cdot 10^9$ $[m^{-3}km^{-1}]$ are located at heights 93.5 and 99 km. The electron density vertical distribution coincides with its gradient (curve 2) showing features at 94 and 99 km with maximums $50 \cdot 10^9$ $[m^{-3}]$ and $25 \cdot 10^9$ $[m^{-3}]$.

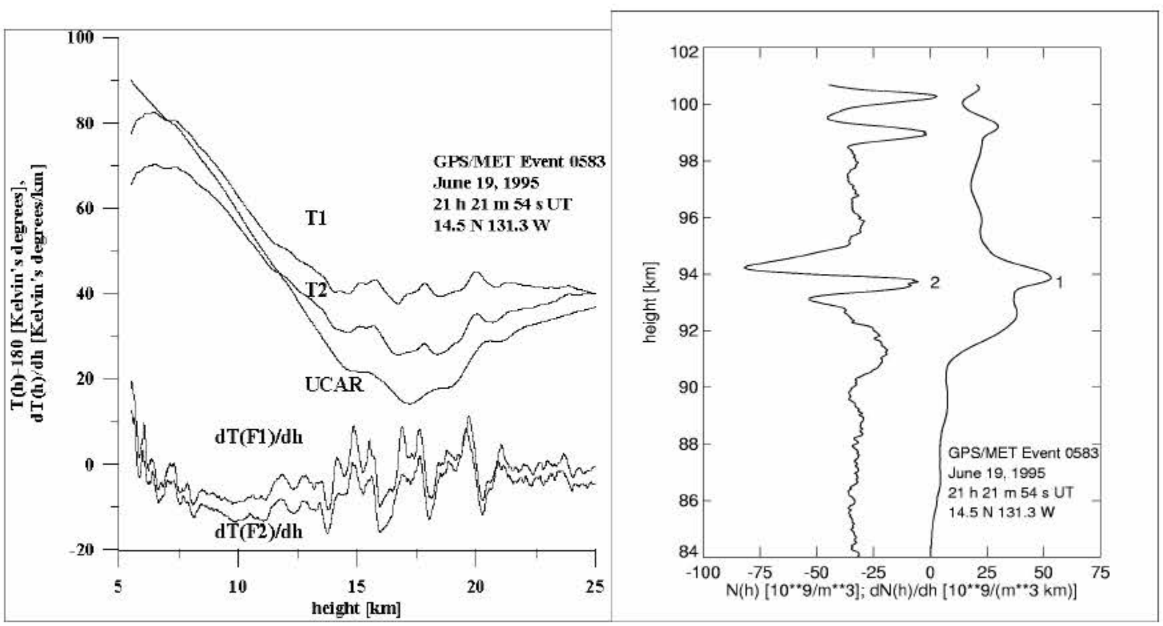

Figure 3. Profiles of (a) temperature and (b) electron density and their gradients. Some curves are displaced for comparisons (Adopted from Liou et al. 2002b).

New 3-D vector radio holographic equations are presented for improving the accuracy of occultation data processing (Pavelyev et al. 2002c). Figure 4 shows examples of radio images of the atmosphere and the Earth's surface. Figure 4 (a) shows radio image of the mesosphere near 56.5 km with only one sharp spike because of a single ray propagation mode. The vertical width of the spike is about 50-70 m. It corresponds to an angular resolution of about 17-23 micro-radians. The broadening of the angular spectrum in the upper atmosphere may be related to the effects of turbulence. The radio brightness distribution in the boundary layer at a height of 1 km is shown in Figure 4 (b). One pixel in the angular spectrum corresponds to a 0.004-mrad variation in the arrival angle and a 12-m change in the minimum height of the ray above the terrestrial surface. Negative-height values correspond to the signals reflected from the Earth's surface. The main peak corresponds to a ling-of-sight radio occultation signal. A very broad pedestal of the radio image corresponds to a conjunction of the reflected and tropospheric signals in the boundary layer. The intensity of the pedestal is compared with the level of signal of the main ray. Figure 4 suggests that the radio holographic focused synthetic aperture method may resolve in detail the one-dimensional vertical radio images of the atmosphere with a scale of 20-50 meters, which corresponds to a spatial resolution of about 1/10 of the Fresnel's zone size.

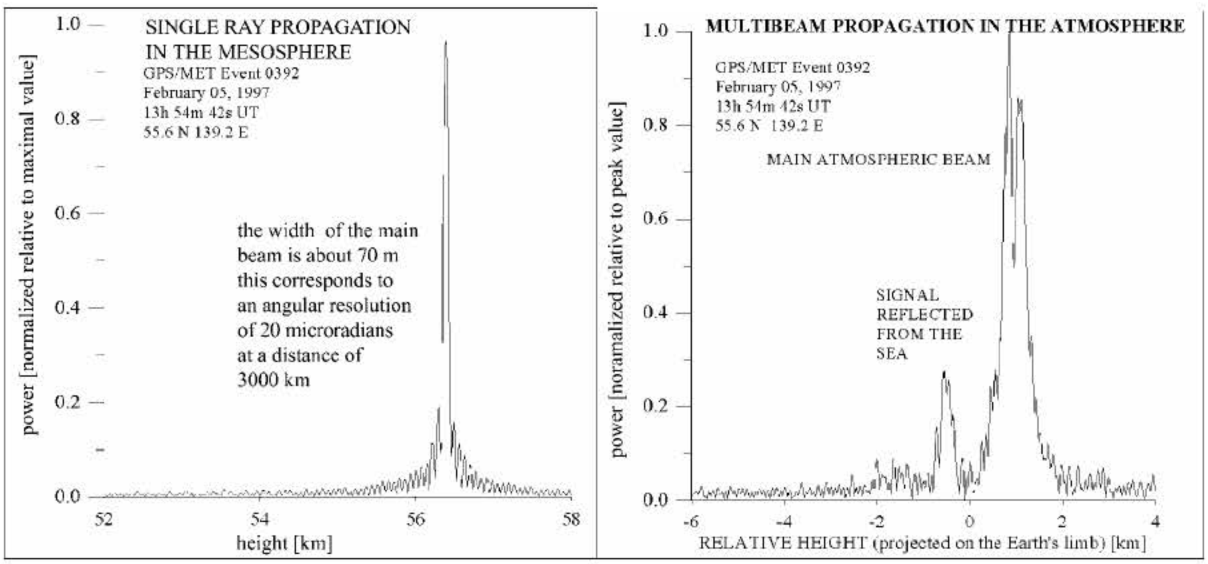

Figure 4. (a) Radioholographic images of the atmosphere at height 56 km for single ray mode. (b) Radioholographic images of the atmosphere and the sea surface. Negative heights correspond to surface reflected signals [Adopted from Pavelyev et al. 2002c].

Except for the work with scientific significance, the things that we learned during the past year are fourfold. First, a field campaign was conducted to investigate the capability of mountain-based occultation approach for measuring atmospheric profiles in May 2002. The experiment failed due to unawareness of GPS receiver's failure to record high sampling rate (50 Hz) data. The failure was found out after the trip and latter fixed. Special care must be done before field campaigns. Second, the tomographic model that we developed to reconstruct 3D wet refractivity structures of the troposphere using ground-based GPS measurements is a simple one (Lin 2002; Lin et al. 2002). The model must be realized by taking into account of more realistic situations to make the model useful in practice. Third, due to a lack of sampling rate data, it is difficult to improve much of our knowledge in physical characteristics of the ionosphere (Tsai 2002). Higher sampling rate of GPS data such as 20 Hz or 50 Hz are required. We are collecting 50 Hz sampling rate GPS data for further investigations of ionospheric irregularities.

Lastly, it is shown that amplitude channel of RO signals may be used independently from phase channel to retrieve the vertical profiles of the refractivity gradient in the atmosphere and electron density in the ionosphere. Radio occultation method of retrieving vertical profile of $dN_e(h)/dh$ is important because Earth-based tools usually give only the vertical profile $N_e(h)$ up to its maximum. The form of this profile above maximum is not available for most Earth-based observational means. Observation of the vertical temperature gradient in the atmosphere and electron density in the mesosphere are useful for revealing interactions of internal waves in the stratosphere and lower ionosphere. This opens new perspectives for simultaneous monitoring of natural processes in the atmosphere and lower ionosphere by radio occultation method.

IMPACT/APPLICATION

GPS/MET is a successful proof-of-concept mission. COSMIC that will consist of six low earth orbit satellites will have a significant impact on meteorology, ionosphere, and climate research. High-quality occultation data processing algorithms will be very crucial to help the COSMIC mission achieve its ultimate goals. In addition, the accomplishments of the secondary objectives will play a key role to link the large-scale observations from the LEO satellites to regional and local space and weather activities for improvements of our understanding on the related sciences and eventually to advance our capabilities in predicting space and weather forecasting.

TRANSITIONS

Products of the electron density profile would be used together with TIP measurements by Dr. Ken Dymond at NRL to determine 2-dimensional density structures in the ionosphere. They may also be used by other space scientists to conduct space weather research through assimilating the retrievals into numerical space weather models. Products of the atmospheric variables profiles are being integrated into numerical weather models by Prof. Ching-Yung Huang at National Central University to improve weather forecasting.

RELATED PROJECTS

The PI is a Principal Investigator of the project “Retrieval and validation of neutral atmospheric parameters from ROCSAT-III” under grant NSC90-2111-M-008-047-AGC (90/08~92/07, ~USD 35,000/year) sponsored by National Science Council, Taiwan. This NSC-support project provided an extra grant of ~USD 30,000 to support Prof. Pavelyev’s visiting to CSRSR for five months. CSRSR provided more than USD 40,000 for the purchase of surveying GPS receivers in addition to the support of all kinds of facilities.

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